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UNITED STATES INVENTION PATENT APPLICATION

FOR

MICRO LIQUID CRYSTAL DISPLAYS

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates micro liquid crystal displays that use digital and reflective technology. The invention may be used to produce high quality static as well as dynamic real time color field micro images on an active pixel matrix.

2. Background Information

Conventional flat-panel displays use electroluminescent materials or liquid crystals in conjunction with incident light to produce high quality images in products such as digital wristwatches, calculators, panel meters, thermometers, and industrial products. Liquid crystals are a state of matter that mixes the droplet or pouring property of a liquid and the long-range order property of a solid. This combination allows an optical activity having a magnitude without parallel in either solids or liquids. Further, when a magnetic or electrical field is applied normal to the liquid crystal material, the liquid crystal material forms a localized monocrystal that is polar in character. This localized polarization of the liquid crystal material affects the travel path of light incident to the liquid crystal material. By controlling the electrical field applied across the liquid crystal material, the travel path of light incident to the liquid crystal material can be controlled to help produce high quality images.

Modern approaches for developing high quality liquid crystal displays (LCDs), also referred to as liquid crystal spatial light modulators (SLMs), utilize an active-matrix approach where thin-film transistors (TFTs) are operationally co-located with a matrix of LCD pixels. The active-matrix approach using TFT-compatible LCDs eliminates cross-talk between pixels to allow finer gray scales. For example, see U.S. patent no. 5,767,828 entitled Method and Apparatus for Displaying Grey-Scale or Color Images from Binary Images and invented by an inventor of the below disclosed invention.

Flat-panel displays employing LCD panels generally include five different layers: A white light source, a first polarizing filter that is mounted on one side of a circuit panel on which the TFTs are assembled in arrays to form pixels, a filter plate containing at least three primary colors arranged into pixels, and a second polarizing filter. A volume between the circuit panel and the filter plate is filled with a liquid crystal material. U.S. patent no. 5,868,951 entitled Electro-Optical Device and Method and co-invented by an inventor of the below disclosed invention relates to flat-panel displays.

Nematic liquid crystal material is frequently used in LCDs since its properties are well understood and it is easy to align. This material will not rotate polarized light when an electric field is applied across it between the circuit panel

and a ground affixed to the filter plate. The first polarizing filter generally converts the incident light into linearly polarized light. When a particular pixel of the display is turned on, the liquid crystal material rotates the polarized light being transmitted through the material. Thus, light passes through the filter plate and is detected by the second polarizing filter.

Conventional liquid crystal displays such as amorphous TFT and super-twist nematic (STN) displays employ large external drive circuitry. However, the amorphous silicon transistors of conventional liquid crystal displays lack the electron mobility and leakage current characteristics necessary for micro liquid crystal displays. Moreover, size and cost restraints for micro liquid crystal displays generally require the drive circuitry of an integrated circuit to be integrated into the display along with the pixel transistors. Because the drive circuitry must be fabricated on the display substrate, micro displays are generally limited to high quality transistor technology such as single crystal (x-Si) and polysilicon (p-Si).

Micro display technologies can roughly be divided into two types: transmissive and reflective. Transmissive micro displays include polysilicon TFT displays. Polysilicon TFT displays dominate display technology in high-end projection systems and are also used as viewfinder displays in hand-held video cameras.

They are usually based on twisted nematic (TN) construction.
See U.S. patent no. 5,327,269 entitled Fast Switching 270 Degree
Twisted Nematic Liquid Crystal Device and Eyewear Incorporating
the Device and invented by an inventor of the below described
5 invention.

The aperture ratio of a transmissive micro display is
obtained by dividing the transmissive area by the total pixel
area. High resolution polysilicon displays such as Super Video
Graphics Array (SVGA) are limited to what is considered larger
10 micro displays having 0.9 - 1.8 inch diagonal (22.9 - 45.7
millimeter diagonal). This is because the area required by the
pixel transistors and the addressing lines reduces the aperture
ratio. Aperture ratios for polysilicon displays are usually
around 50%. Single crystal silicon transmissive displays are
15 similar to polysilicon TFT displays but use a transistor lift-
off process to obtain single crystal silicon transistors on a
transparent substrate.

Reflective micro displays are usually based on single-
crystal silicon integrated circuit substrates with a reflective
20 aluminum pixel forming a pixel mirror. Because it is
reflective, the pixel mirror can be fabricated over the pixel
transistors and addressing lines. This results in an aperture
ratio (reflective area/absorptive area) that is much larger than
polysilicon displays. Aperture ratios for reflective displays

can be greater than 90%. Because of the large aperture ratio and the high quality silicon transistors, the resolution of a reflective micro display can be very high within a viewing area that is quite small.

5 There are several different liquid crystal technologies currently used in reflective micro displays. These include ferroelectric liquid crystal (FLC), polymer disbursed liquid crystal (PDLC), and nematic liquid crystal. Size and resolution of reflective micro displays may range from 0.25 inch diagonal (QVGA) to 0.9 inch diagonal (SXGA) (6.4 - 22.9 millimeter diagonal). Reflective micro displays are limited in physical size because as the size increases the cost increases and yield decreases.

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For further background in this area, see Douglas J. McKnight, et al., 256 x 256 Liquid-Crystal-on-Silicon Spatial Light Modulator, 33 Applied Optics No. 14 at 2775-2784 (May 10, 1994); and Douglas J. McKnight et al., Development of a Spatial Light Modulator: A Randomly Addressed Liquid-Crystal-Over-Nmos Array, 28 Applied Optics No. 22 (Nov. 1989).

SUMMARY OF THE INVENTION

The invention relates to liquid crystal displays and method of making liquid crystal displays. One liquid crystal display invention has as an element an optically transmissive first
5 substrate that may be positioned to receive light incident from the light source. A reflective second substrate is positioned adjacent to this first substrate. The second substrate has an active area that may include a circuit panel and a perimeter seal area surrounding that active area. To separate the first substrate from the second substrate, spacers are configured about the perimeter seal area of the second substrate. Between the first substrate and the second substrate is a liquid crystal material. Other embodiments are disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a planar side view of an optically transmissive substrate and a semiconductor substrate or wafer;

Figure 2 is a perspective top view of the substrates of

5 Figure 1;

Figure 3 is a planar side view of the substrate and wafer after the subsequent processing step of depositing a conductive coating on an optically transmissive substrate;

Figure 4 shows the subsequent processing step of depositing alignment layers on one surface of the substrate and the wafer;

Figure 5 schematically illustrates an apparatus for rubbing the surface of the alignment layers with a velvet cloth;

Figure 5 shows a cylinder having a velvet cloth on its surface;

Figure 6 shows exemplary rub directions for opposing alignment layers of a substrate and a wafer 115;

Figure 7 schematically illustrates a planar top view of a wafer including a plurality of micro display areas;

Figure 8 illustrates one micro display area of the semiconductor wafer;

Figure 9 shows a cross section of a display area taken through line A-A of Figure 8;

Figure 10 shows the wafer after the deposition of cross-over material;

Figure 11 shows an optically transmissive substrate and a wafer assembled together in a mechanical press;

Figure 12 shows that a shim plate is flexible enough to conform to the presence of foreign particles;

5 Figure 13 illustrates the cross-over material piercing the alignment layers;

Figure 14 illustrates the use of a conformal bag press;

Figure 15 illustrates how the gap may also be used as an entrance for liquid crystal display material;

10 Figure 16 shows the optically transmissive substrate/wafer assembly lowered into a liquid crystal material bath;

Figure 17 shows liquid crystal material forced into the cell gap due to pressure differential;

15 Figure 18 illustrates a compensating or retarder film laminated to the entire surface of the transmissive substrate;

20 Figure 19 shows the street areas between the individual display devices;

Figure 20 shows the case where the transmissive substrate is square;

20 Figure 21 illustrates how the semiconductor wafer is diced from the backside;

Figure 22 shows the backside of the wafer after the step of partial cutting of all of the semiconductor wafer;

Figure 23 shows the assembly after the scribing of the glass material in an X-direction;

Figure 24 shows the assembly after the scribing of the glass material in a Y-direction;

5 Figure 25 shows a top view of the assembly with the pattern-side of wafer facing in the up position;

Figure 26 shows an embodiment where the perimeter of the transmissive substrate follows the generally round perimeter of the wafer;

10 Figure 27 shows material removed from the wafer to provide X- and Y-registration;

Figure 30 shows a singulated device put in a vacuum chamber;

15 Figure 31 shows liquid crystal material forced into the display area due to pressure differential;

Figure 32 shows a singulated device position with the fill port facing up within a chamber;

Figure 33 illustrates the chamber in the pressurized state;

20 Figure 34 illustrates a cross-section of an individual display from an X-direction;

Figure 35 illustrates a cross-section of an individual display from an Y-direction;

Figure 36 shows the micro liquid crystal display ready to be packaged into a micro liquid crystal display panel;

Figure 37 shows a single-chip radio manufactured by Lucent Technologies Inc.;

Figure 38 illustrates a size comparison between a U.S. penny, a conventional ceramic filter, and a miniature RF filter;

5 and

Figure 39 shows a tank circuit having a miniature inductor and capacitor.

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DETAILED DESCRIPTION OF THE INVENTION

In the following description, numerous specific details are set forth such as specific materials, processing steps, processing parameters, etc., in order to provide a thorough understanding of the invention. One skilled in the art will recognize that these details need not be specifically adhered to practice the claimed invention. In other instances, well known processing steps, materials, etc., are not set forth in order not to obscure the invention. As indicated under MPEP 2164.01, a patent need not teach, and preferably omits, what is well known in the art.

The following describes an embodiment of forming a liquid crystal display, cell, or device, in accordance with the invention. **Figure 1** shows a planar side view of optically transmissive substrate 100 and semiconductor substrate or wafer 115. In this embodiment, the character of substrate 100 is optically transmissive where optically transmissive substrate 100 may serve as a cover that is positioned to receive light incident from a light source (not shown). Moreover, optically transmissive substrate 100 may be approximately 1.1 millimeters (mm) thick. Optically transmissive substrate 100 may include cover glass material 102, such as Corning 1737 industrial grade boroaluminosilicate glass available from Applied Films Corporation of Boulder, Colorado. With the processing

temperature ranges for making liquid crystal displays being between 0 degrees Celsius (deg. C) and 300 degs. C, Corning 1737 is a preferable glass material because it is readily availability and its coefficient of thermal expansion (Corning 1737 CTE = 37.6×10^{-7} / deg. C) is very close to that of silicon. In this embodiment, optically transmissive substrate 100 may include a film of retarder layer 110 laminated to glass material 102 as seen in **Figure 1** and **Figure 18**. Retarder layer 110 serves to compensate for residual birefringence in liquid crystal during the "on" (black) state. Retarder layer 110 improves the contrast of the display.

Figure 1 also shows semiconductor wafer 115 that contains, for example, a plurality of flat-panel display circuitry. The circuitry preferably is based on single-crystal silicon integrated circuit substrate technology with a reflective pixel layer. In the embodiment shown, the individual display circuitry of wafer 115 is, for example, reflection mode circuitry. This reflection is illustrated in **Figure 1** by reflective pixel layer 125. Reflective pixel layer 125 is fabricated preferably out of aluminum over the mode circuitry having pixel transistors and addressing lines within backplane 120 of wafer 115. In this embodiment, the aluminum provides a reflective character to pixel layer 125. Other materials such as gold or silver that are capable of reflecting sufficient

undiffused light to form a virtual image so as to faithfully reflect or give a true picture may be used. It is to be appreciated that the invention is not limited to semiconductor wafer arrays. Other substrate arrays such as, for example, silicon on insulator (SOI) arrays, can also be used to form the individual display devices of the invention.

Figure 2 is a perspective top view of the substrates of **Figure 1**. **Figure 2** shows cover glass 102 situated above circuitry pattern-side 117 of semiconductor wafer 115. Wafer 115 is shown with reflective pixel layer 125 over a plurality of reflection mode display circuitry revealed on pattern-side 117 of backplane 120.

Figure 3 is a planar side view of substrate 100 and wafer 115 after the subsequent processing step of depositing conductive coating 130 on optically transmissive substrate 100. In one embodiment, optically transmissive substrate 100 is glass material 102 made of Corning 1737 glass having conductive coating 130 of Indium-Tin-Oxide (ITO) applied to one side. ITO is a transparent metal oxide coating that may be deposited on glass material 102 by way of a sputtering operation. ITO is an industry standard conductive film because of its high optical transmission and low electrical resistance. ITO preferably is applied to the Corning 1737 glass at a coating thickness of 190 angstroms (Å) nominal. At 190 angstroms (Å), conductive coating

130 exhibits a sheet resistance of 60 ohms/square minimum to 125 ohms/square maximum and a transmission of 84% minimum at 550 nanometers (nm). U.S. 5,230,771, U.S. 5,171,401, and 5,032,221 were co-invented by an inventor of this patent and relate to plasma etching of Indium Tin Oxide.

In this embodiment, conductive coating 130, such as ITO layer, is not patterned. It has been found that depositing conductive coating 130 without patterning, simplifies the manufacturing process because it eliminates the need for photolithography processing. Importantly, un-patterned cover glass substrate 100 also simplifies the assembly process because it allows for a simple mechanical alignment of substrate 100 and wafer 115 rather than a more complicated camera-assisted alignment as is conventionally employed.

Figure 4 shows the subsequent processing step of depositing alignment layers 135 on one surface of optically transmissive substrate 100 and on a complementary surface of semiconductor wafer 115. In one embodiment, alignment layer 135 is a polyimide material manufactured by Nissan Chemical Industries of Tokyo, Japan. Polyimide is an industry standard material for nematic liquid crystal alignment layers because of its easy of application, its excellent anchoring of liquid crystal molecules, and its support of a wide range of pre-tilt angles. In one embodiment, alignment layer 135 is NISSAN SE-7492™

polyimide material purchased as a solution to be spin-coated on substrate 100 and substrate 115. In this embodiment, the polyimide initially has a 6% solids content. Prior to deposition onto optically transmissive substrate 100, the polyimide is diluted with Nissan Solvent 21 (or Nissan Solvent 2M) to a 2% solid solution. NISSAN SE-7210™ may also be used for alignment layer 135.

In the application of alignment layer 135, optically transmissive substrate 100 and semiconductor wafer substrate 115 are spun-coated with a 2% solids polyimide solution. Spin coating is a method of film deposition that provides a uniform coating across the surface of the substrate. Spin coating equipment is widely used in the display processing industries.

After substrate 100 and wafer 115 are coated with alignment layers 135, the polyimides of alignment layers 135 are cured. The substrates first receive a low temperature soft bake (e.g., 100 deg. C on metal surface in convection oven) to remove the solvents, then a high temperature hard bake (e.g., ramp from 100 deg. C to 180 deg. C in 10 minutes; total hard bake cycle time 60 minutes) to fully cure the polyimide. The cure processes of the invention preferably are performed in a clean room convection oven.

One purpose of alignment layers 135 is to establish the optical reference axis of the liquid crystal material. Once

alignment layers 135 are deposited and cured on substrate 100 and wafer 115, alignment layers 135 may be aligned in accordance with the desired light rotation of the liquid crystal material molecules that will form part of the individual display. The alignment direction of the liquid crystal molecules is obtained by means of rubbing the exposed surface of alignment layers 135 with a velvet cloth.

Figure 5 schematically illustrates apparatus 148 for rubbing the surface of alignment layer 135 with velvet cloth 145. As a soft fabric, such as silk, rayon, or nylon, velvet is preferred to impart the alignment direction because of its smooth, dense pile and a plain underside. **Figure 5** shows a cylinder 142 having velvet cloth 145 on its surface. Cylinder 142 rotates, in this case, in a clockwise direction. Substrate 100 or 115 having alignment layer 135 rests on a horizontally moving stage 140 so that alignment layer 135 of substrate 100 or 115 comes in contact with velvet cloth 145 of cylinder 142. In one embodiment, cylinder 142 rotates at a speed of 400 revolutions per minute and has a motor drag of 37 millivolts. Stage 140 moves in a horizontal direction at a speed of approximately 0.75 inches per second yielding a table stage motion axis relative to cylinder rotation axis of 90 degrees and rub depth of 0.020 inches. A suitable material for cloth 145

may be, for example, the YA-20-R rayon cloth produced by Yoshikawa Chemical Company of Tokyo, Japan.

Figure 6 shows exemplary rub directions for opposing alignment layers 135 of substrate 100 and wafer 115 as imparted via apparatus 148 of **Figure 5**. It is to be appreciated that the depth and direction of the rub is a function of, for example, the liquid crystal molecules chosen for the individual display. The above description of the rub process of alignment layers 135 is presented in detail herein by way of explanation and not by way of limitation, in accordance with the description of the particular liquid crystal display described herein.

Once alignment layers 135 are deposited on substrate 100 and 115 and rub directions are established on alignment layers 135, spacers are applied to semiconductor wafer 115. As described in connection with **Figure 7**, one purpose of applying spacers is to create cell gap 207 (**Figure 11**) for the placement of liquid crystal molecules between substrate 100 and substrate 115.

In most prior art display applications, spacers are dispersed randomly across the entire display substrate, including the viewing area. In large area displays, for example, the spacers in the viewing area maintain spacing uniformity because large glass substrates overlying display circuitry can warp. Spacers in the viewing area of a display

are undesirable since they can reduce the contrast of the display by not rotating the localized incoming light from a white light source.

Figure 7 schematically illustrates a planar top view of wafer 115 including a plurality of micro display areas 155. In one embodiment, there are 86 micro display areas 155. **Figure 7** shows a perimeter seal material 150 containing spacers 152 (**Figure 8**) surrounding the perimeter of each of a plurality of display area 155 as well as surrounding the inside perimeter of wafer 115. Perimeter seal material 150 may be a thermal cure adhesive as discussed below and spacers 152 may be silica spheres.

Material 150 preferably comprises white silica spheres initially in a dry state. To form perimeter seal material 150, this dry spacer material is first mixed with a solvent, for example the solvent known as "DEC", in a concentration of approximately 0.072 grams spacer material to 1.0 gram DEC. The materials are mixed in a container. The mixture is then placed in an ultrasonic bath for fifteen minutes to thoroughly mix the particles in the solvent and to break up any clumps of material. The solvent and spacer mixture is then mixed with 20 grams of perimeter seal material. In this embodiment, perimeter seal material 150 is a heat-cured adhesive. It is to be appreciated

that there are many suitable adhesives including, but not limited to, heat- and ultraviolet-cured adhesives.

Perimeter seal material 150 containing spacers 152 may be applied using a syringe having a fluid dispensing system, such as one manufactured by Asymtek of Carlsbad, California. An automatic dispensing system may consist of a syringe mounted above wafer substrate 115 having full X- and Y-motion capabilities. Perimeter seal material 150 including spacers 152 may then be dispensed from a needle, for example a 0.006 inch inside diameter lavender needle, and the flow of material may be controlled pneumatically, for example at a dispensing speed of 0.28 inches per second and a dispensing pressure of 24 pounds per square inch with a needle height of 0.003 inches. In this manner, a consistent 0.5 millimeter perimeter seal line width is obtained for perimeter seal area 165.

Perimeter seal material 150 containing spacers 152 is dispensed in the perimeter seal areas 165 as shown in **Figure 8**. As shown in **Figure 7**, a pattern (perimeter seal material 150 encapsulating spacers 152) is also dispensed at the edge of wafer 115 in the "unused" areas of wafer 115. This additional edge pattern is a support structure that works to prevent wafer 115 from collapsing at its edges. Without this support structure around the edge of wafer 115, wafer 115 cannot adequately support the force required to press together wafer

115 and optically transmissive substrate 100. Without sufficient press force, a non-uniform cell gap 207 that is collapsed at the edge of wafer 115 will be formed. The perimeter seal around the outer edge of wafer 115 also works as
5 a seal to prevent water from entering the cell gap during a wafer dicing process.

The next step in forming a LCD display in accordance with an embodiment of the invention is the deposition of a cross-over material on each display area 155 of wafer 115. Recall that
10 when a magnetic or electrical field is applied normal to the liquid crystal material, the liquid crystal material forms a localized monocrystal that is polar in character. A cross-over may be thought of as an adhesive material or epoxy into which
15 conductive material is disbursed so as to aid in creating an electrical path between the reflection mode display circuitry that resides below the reflective pixel layer of the wafer and the conductive coating layer attached to the glass cover. In
20 other words, cross-over material 170 communicates the cover glass drive voltage from reflective pixel layer 125 of wafer 115 to conductive coating 130 of substrate 100. Conventionally, the cross-over material is made of silver particles or gold-coated plastic particles.

To conventionally create this electrical path, alignment layers 135 are first removed or etched away to create a path in

reflective pixel layer 125 and in conductive coating 130. Then, the cross-over material is adhered to this path in reflective pixel layer 125 and brought into contact with the path in conductive coating 130. Alternatively, a special mask

5 conventionally is created to mask off the cross-over paths prior to applying the polyimide.

In an embodiment of the invention, cross-over material 170 preferably contains particles made of conductive nickel. The nickel particles surprisingly permit cross-over material 170 to break through the polyimide alignment layers 135 to create the desired electrical path. Thus, the use of nickel particles eliminates the need to etch away alignment layers 135 or use a mask prior to applying alignment layers 135.

To form an embodiment of cross-over material 170, nickel particles having 2.0 micron nominal diameters are first mixed with a solvent, for example DEC, in a concentration of approximately 0.669 grams of cross-over material to 1.0 grams of DEC. The materials are mixed in a container and sealed. The mixture is then placed in an ultrasonic bath for fifteen minutes to thoroughly mix the particles in the solvent and to break up any clumps of material. The solvent and nickel particle mixture is then mixed with 20 grams of perimeter seal material. Similar to perimeter seal material 150, an Asymtek fluid dispensing machine may be used to dispense cross-over material 170. In one

crystal display material (material 220, **Figure 16**; material 310, **Figure 30**; and material 311, **Figure 32**) into display area 160.

As shown in **Figure 10**, the matrix of spacers 152 may include more than one spacer 12 across area 165.

5 Spacers 152 such as shown in **Figure 8** are added to perimeter seal area 165 to create cell gap 207 (**Figure 11**) between wafer 115 and optically transmissive substrate 100. Cell gap 207 is created to permit placement of liquid crystal material between wafer 115 and optically transmissive substrate 100. Perimeter seal material 150 seals the gap between wafer 115 and substrate 100 along the pattern of perimeter seal area 165 to capture liquid crystal material within each viewing area 160. Similar to fill port area 167 of **Figure 8**, gap 153 of **Figure 7** is left free of perimeter seal material 150 and spacers 152. This permits trapped air to escape as wafer 115 is affixed to optically transmissive substrate 100. Gap 153 may also be used as an entrance for liquid crystal display material 220 (**Figure 15**).

20 **Figure 9** shows a cross section of display area 155 taken through line A-A of **Figure 8**. **Figure 9** shows display area 155, display area 160, perimeter seal area 165, cross-over material 170, and spacers 152. The outside diameter of spacers 152 is a function of the desired thickness of the liquid crystal material layer, such as cell gap 207 of **Figure 11**. In one embodiment,

spacers 152 may be 2.1 micron silica spheres from Bangs Laboratories of Fishers, Indiana. Spacers having an outside diameter ranging from 1.5-3.0 microns are used in this embodiment. Spacers 152 are mixed with perimeter seal material where the mixture is applied to perimeter seal area 165 of display area 155 of wafer 115 and to the inside perimeter of wafer 115 (**Figure 7**) during a perimeter seal application process.

As noted above, gap 153 of **Figure 7** is left in the wafer perimeter seal to allow air to escape during a subsequent press and cure process. Gap 153 also permits the positioning of liquid crystal material between wafer 115 and optically transmissive substrate 100 prior to dicing or "singulating" wafer substrate 115. Gap 153 is later filled with an adhesive to complete display area 160.

Figure 10 shows wafer 115 after the deposition of cross-over material 170. Cross-over material 170 provides, in one manner, electrical contact between wafer 115 and optically transmissive substrate 100, such as seen in **Figure 34** and **Figure 35**. In the embodiment where spacers 152 have an outside diameter of 2.1 microns, cross-over material 170 preferably contains 2.0 micron nominal diameter nickel particles purchased from Goodfellow, Inc. of Cambridge, England. Other conductive particles are acceptable substitutes for nickel where supplied

in a particle form having similar conductive characteristics and break-through characteristics as nickel. In this embodiment, because conductive coating 130 of transmissive substrate 100 has no patterning, a mechanical alignment method can be used during assembly as shown in **Figure 10**.

Once optically transmissive substrate 100 and wafer 115 are assembled together, the substrates may be placed in mechanical press 180 as shown in **Figure 11**. Mechanical press 180 consists of two heated aluminum plates 185 and 187 hinged together in a clamshell fashion wherein each shell is parallel to one another. In this embodiment, bottom plate 187 includes an inflatable bladder 195. Inflatable bladder 195 provides the direct pressure required to assemble together transmissive substrate 100 and wafer 115.

In one embodiment, a clean 1.1 millimeter thick borosilicate glass shim plate 200 having approximately the same or larger surface area as optically transmissive substrate 100, for example, a 7-inch square surface area, is placed over bladder 195 of bottom plate 187. Wafer 115 and optically transmissive substrate 100 are thoroughly cleaned. First wafer 115 and then substrate 100 each are stacked on glass shim plate 200. Pressure is then applied to wafer 115 and transmissive substrate 100 by inflating the bladder against glass shim plate 200. The inflating bladder 195 is restricted by plate 185 and

plate 187 forces wafer 115 and transmissive substrate 100 together. Wafer 115 and substrate 100 are pressed together in such a manner that cross-over material 170 pierces each alignment layer 135 to make contact between conductive coating 130 and reflective pixel layer 125 as seen in **Figure 13**. In one embodiment, wafer 115 and substrate 100 are pressed together so that they are separated by a distance of approximately 2 microns at cell gap 207.

As shown in **Figure 11**, optically transmissive substrate 100 has a larger surface area than semiconductor wafer 115, for example, seven-inch square optically transmissive substrate 100 versus six-inch diameter wafer 115. To prevent glass shim plate 200 from flexing at assembly edge 202 when bladder 195 is inflated, shims 205, for example glass shims, of the same thickness as wafer 115 are placed at the periphery of wafer 115 on plate 200.

The retaining method of combining glass shim plate 200 with inflatable bladder 195 and shims 205 results in a uniform cell gap 207 across the assembly, between transmissive substrate and wafer 115. The uniform cell gap 207 across the assembly is better than that which would be achieved using only hard plates or an inflatable bladder without a glass shim plate or shims.

Glass shim plate 200 acts as a semi-rigid, two-dimensional support beam distributing the pressure applied by bladder 195

only to areas where spherical spacers 152 are present between substrate 100 and wafer 115. Because spacers 152 are present only in perimeter seal areas 165, the pressure applied by the mechanical press is applied primarily to the seals and not to the interior, e.g., cell gap 207, of individual display devices. The application of pressure only to the seals prevents wafer 115 from deforming in those areas not having spacers 152.

Semi-flexible shim plates 200 serve a second function. Shim plate 200 acts as a semi-flexible cover to compensate for any imperfections or foreign material that may be present. **Figure 12** illustrates an example where a foreign particle 208 is trapped between shim plate 200 and wafer 115. **Figure 12** shows that shim plate 200 is flexible enough to conform to the presence of foreign particle 208 and not disrupt the even distribution of pressure applied to the perimeter seal areas of wafer 115. A shim plate of glass serves this forgiving purpose. If shim plate 200 were a rigid material, such as aluminum or steel, any foreign particles located anywhere between substrate 100 and wafer 115 could cause excessive pressure at the particle and insufficient pressure in other areas. This would result in a localized area that is over pressed and a large area that is under pressed. A semi-flexible shim plate 200 will flex and only an insignificantly small area around foreign particle 208 will arguably be insufficiently pressed.

A preferred alternate embodiment to the press assembly technique of **Figure 11** and **Figur 12** will now be described.

Figure 14 illustrates the use of conformal bag press 201. Once optically transmissive substrate 100 and wafer 115 are assembled together as shown in **Figure 10**, the assembly may be placed in conformal bag 203 of bag press 201 as shown in **Figure 14**.

Conformal bag 203 may be a rectangular shaped, high temperature nylon bag. At this point, tube 206 extending from vacuum pump 204 is coupled to bag end 209 of conformal bag 203. Vacuum pump 204 may be a food industry, commercial quality sealer.

With vacuum pump 204 activated, air is drawn from the inside of conformal bag 203. As air is drawn from the inside of conformal bag 203, conformal bag 203 closes about substrate 100 and wafer 115. The compression forces of conformal bag 203 are applied equally about each surface of substrate 100 and wafer 115. Since the force per unit surface area is greatest on the large, exposed surfaces of retarder layer 110 and backplane 120, retarder layer 110 and backplane 120 move vertically towards one another substantially while maintaining their original, complementary alignment. As the nickel particles within cross-over material 170 are urged into alignment layers 135, the polyimide material of alignment layers 135 separates until cross-over material 170 contacts reflective pixel layer 125 and conductive coating 130. This vacuum bag method is preferred to

the clam shell method because, for example, conformal bag 203 easily adjusts to particles trapped between conformal bag 203 and the assembly of substrate 100 and wafer 115.

With a vacuum drawn into sealed, conformal bag 203, conformal bag 203 along with the assembly of substrate 100 and wafer 115 is placed into an oven to cure the adhesive of perimeter seal material 150 and cross-over material 170. Preferably, they remain in the oven at 160 deg. C for 60 minutes. In an alternate embodiment, the air within conformal bag 203 is evacuated and conformal bag 203 is back filled with another gas, such as nitrogen, helium, or argon, to displace any oxygen. This back filled gas is then evacuated by vacuum pump 204 to compress substrate 100 and wafer 115 together.

With the adhesives cured and cross-over material 170 in a position to communicate the cover glass drive voltage from reflective pixel layer 125 of wafer 115 to conductive coating 130 of substrate 100, the cell gaps between the individual display area 155 of wafer 115 and optically transmissive substrate 100 may be filled with liquid crystal material before individual display devices 300 (**Figure 28** and **Figure 29**) are cut and separated. This filling process is shown in **Figure 16** and **Figure 17**. The assembly (optically transmissive substrate 100 and wafer 115) may be filled by a vacuum fill method common to filling nematic liquid crystal displays. The entire assembly is

put in a vacuum chamber 210. Chamber 210 is evacuated until the pressure reaches approximately 10^{-1} Torr. In connection with **Figures 7-9**, a perimeter seal application process was described for placing perimeter seal material 150 including spacers 152 around wafer 115. As stated, a perimeter seal adhesive 150 is applied around the entire wafer 115 except for evacuation gap port 153 to allow air to escape during the press process. Gap 153 now may be used to allow the entrance of liquid crystal material in the cell gap between the assemblies.

As shown in **Figure 16**, the optically transmissive substrate/wafer assembly is lowered into bath 215 containing liquid crystal material 220. The assembly is lowered into the bath 215 until evacuation port 153 contacts liquid crystal bath 215. Chamber 210 is then pressurized to atmospheric pressure with a gas, such as nitrogen, helium, or argon, but preferably air. As illustrated by way of example in **Figure 8**, each of individual display area 155 has a fill port 167 to allow liquid crystal material to be placed in display area 160 of individual display device 300. The pressure difference between cell gaps 207 of the individual display devices and the ambient, forces liquid crystal material 220 into cell gaps 207 throughout the assembly as illustrate in **Figure 17**. Once liquid crystal material 220 is placed in cell gap 207 of each individual display device 200, the excess liquid crystal material 220 is

cleaned off evacuation port area 153. An ultraviolet cure adhesive then is applied to evacuation port 153 and cured with ultraviolet light to seal the assembly.

Figures 16 and 17 illustrate a process where liquid crystal material is added to the assembly prior to separating the assembly into individual display devices 300. The liquid crystal material fill process can also be accomplished once the individual display are separated from the assembly. This is discussed in connection with **Figures 30 to 33**. In this case, evacuation port 153 is filled with an ultraviolet cured adhesive and cured following just after the press process.

To produce high quality static as well as dynamic real time color field images on an active pixel matrix, the nematic liquid crystal material 220 used in a preferred embodiment should meet several factors. Color field sequential operation requires a fast pixel switching time under low voltage operations. Switching speed is proportional to the square of the cell gap. In order to meet the fast switching time required for color field sequential operations, cell gap 207 should be on the order of two microns. This relative thinness is a factor in selecting the proper viscosity for liquid crystal material 220. As another factor, the liquid crystal cell should be capable of rotating the polarization of reflected light by 90 degrees to obtain bright, high contrast operations. Thus, the liquid

crystal layer performs as a quarter-wave plate in a preferred embodiment.

The viscosity of liquid crystal material 220 should be as low as possible to achieve fast switching speeds. Moreover, in respect to the above factors, the birefringence (Δn or Δn) of the liquid crystal material should be approximately 0.1. To achieve low voltage operations, the threshold voltage of liquid crystal material 220 should be low, such as a dielectric constant anisotropy ($\Delta \epsilon$ or $\Delta \epsilon$) on the order of at least 10.

In addition, to avoid undesirable temperature effects at the upper operating range of the micro LCD, the clearing point of liquid crystal material 220 should be at least 20 deg. C above the highest operating temperatures for the micro LCD. One having ordinary skill in the art of manufacturing liquid crystal material is able to compose a material meeting the above factors for liquid crystal material 220.

After the wafer assembly is pressed and sealed, the exterior surface of optically transmissive substrate 100 is cleaned, for example, with a solvent. If not already applied, an optical film then may be applied to the entire surface of transmissive substrate 100. In one embodiment, compensating or retarder film 110 is laminated to the entire surface of transmissive substrate 100 using a roller-type lamination machine. The lamination is shown in **Figure 18**. Compensating or

retarder film 110 is used, in one sense, to compensate for unwanted birefringence in a display. The film is used to compensate for residual birefringence in the black state that results in a darker black. Compensating or retarder film thus provides an improved contrast between black and white.

Compensating or retarder film 110 must cover the active area of the display after it is completely assembled. In most display applications that use a compensating or retarder film, the compensating or retarder film is laminated to the individual displays after they are separated from the wafer substrate. This is a labor-intensive process for small displays with many displays on a large substrate. The invention teaches a process in which a film, either retarder or polarizer, is laminated to the glass prior to separating the displays. It is to be appreciated that compensating or retarder film 110 can be laminated to each individual display assembly after they are formed and separated.

In street areas 230 between the individual display devices, compensating or retarder film 110 is then removed, using a laser as shown in **Figure 19**. This removal exposes transmissive glass material 102 to allow it to be scribed, for example, using a carbide wheel.

Next, as shown in **Figure 20**, in the case where transmissive substrate 100 is square, a dicing saw may be used to scribe

relative fiducial or alignment marks 240 and 245 on optically transmissive glass substrate 100. To scribe marks 240 and 245, the assembly is placed on the vacuum chuck of a dicing saw with patterned-side 117 (see **Figure 2**) of semiconductor wafer 115 set in the face up position. When the assembly is mounted on the vacuum chuck to cut wafer 115 (i.e., circuitry patterned side 117 of wafer 115 is face down) scribe marks 240 and 245 in transmissive substrate 100 are visible through glass material 102 and may be used for alignment. The camera uses alignment or registration marks 240 and 245 to cut wafer 115 from the backside, since marks 240 and 245 are relative to micro display area 155 of wafer 115.

Next, as shown in **Figure 21**, semiconductor wafer 115 is diced from the backside, which has no patterns visible on wafer 115 to use as registration marks for the dicing process. **Figure 21** shows the assembly placed with optically transmissive substrate 100 face down (i.e., circuitry patterned side 117 of wafer 115 is "down") on the vacuum chuck. Scribed alignment marks 240 and 245 on transmissive substrate 100 are visible through glass material 102 to aid alignment. The backside of wafer 115 is then cut according to the patterning registered by the camera and aligned by registration marks 240 and 245. **Figure 21** shows cut 255 in an X-direction and cut 260 in a Y-direction. **Figure 22** shows the backside of wafer 115 after the

subsequent step of partial cutting of all of semiconductor wafer 115 in an aligned relation to the patterning on the patterned side of wafer 115, using registration marks 240 and 245 as an aid, so that the assembly may be divided or "singulated" into individual display 300. Wafer 115 is partially cut using a water-cooled wafer dicing saw. The depth of the saw blade is set to cut partially through the thickness of wafer 115, in one embodiment, removing enough material to easily divide wafer 115 in a later process, but retaining enough material to prevent water from entering cell gap 207 (**Figure 11**) between wafer 115 and transmissive substrate 100. Wafer 115 is then cut in a wet-sawing process. After the partial cutting, wafer 115 is thoroughly dried.

Optically transmissive glass substrate 100 provides support for semiconductor wafer 115 during the cutting, drying, and handling processes. In addition, optically transmissive substrate 100 prevents wafer 115 from flexing and possibly breaking at the cuts which would allow water to enter the gap between the substrates. Because of the support provided by transmissive substrate 100, the depth of the saw cut can be very close to the thickness of wafer 115 without significant risk of water leakage, for example, approximately 80% of the thickness of wafer 115 can be cut.

Because no patterns are visible on the backside of semiconductor wafer 115, an alternative process to the process described above with reference to **Figures 21** and **22** is to mount the programmable camera beneath the dicing saw. Thus, wafer 115 is placed on the vacuum chuck and aligned to a camera mounted under the vacuum chuck. A marking device with X-Y motion capabilities, such as a laser or carbide needle, contacts the backside of wafer 115 and creates two registration marks on the patterned surface of wafer 115. The registration marks are then used in the cutting process.

After the cutting process and the assembly drying process, a dry cutting process is used to scribe transmissive substrate 100. In the embodiment where optically transmissive substrate 100 is glass material 102, the glass must be scribed using a dry process because, after it is scribed, the assembly has no support to prevent the glass or wafer 115 from cracking. Cracks in either substrate would allow any liquid used in the process to enter cell gap 207 between the substrates, i.e., cell gap 207 where liquid crystal material exists or is to be placed.

To scribe optically transmissive substrate 100 in the embodiment where material 102 is a glass substrate, the assembly is placed with pattern-side 117 of wafer 115 facing n the up direction (optically transmissive substrate 100 side "up") on the vacuum chuck of a carbide wheel type glass scribing machine

such as that manufactured by Villa Precision International. The glass is scribed with the carbide scribe wheel in the locations where the glass will separate, e.g., directly aligned or in an aligned relation with the scribe areas of wafer 115. The glass can also be cut with a laser process. **Figure 23** shows the assembly after the scribing of glass material 102 in an X-direction. Scribing 248 is located in those areas where optically transmissive substrate will separate. In an X-direction, in this embodiment, scribing 248 is in an aligned relation to scribe areas 265 of wafer 115.

Figure 24 shows the assembly after the scribing of glass material 102 in a Y-direction. In a Y-direction, glass material 102 is not scribed directly over scribe areas of wafer 115. Instead, scribing 250 is slightly offset. The offsetting serves to expose a portion of wafer 115 as offset portion 119 for each eventual display. The exposure of offset portion 119 of wafer 115 is done to allow a subsequent step of making an electrical connection to the individual display when the display is packaged. Offset portion 119 is best seen in **Figure 35** and **Figure 36**. Exposed area 119 of the individual display may have bond pads 405 or other contacts coupled to the circuit devices of the individual display as seen in **Figure 36**.

Figure 25 shows a top view of the assembly with pattern-side 117 of wafer 115 facing in the up position (optically

transmissive substrate 100 side "up"). **Figure 25** shows transmissive substrate 100 scribed in areas where transmissive substrate is to be separated, i.e., scribing 248 in an X-direction directly aligned with or in an aligned relation with the scribe areas of wafer 115 and scribing 250 in a Y-direction offset from the corresponding Y-axis scribe areas of wafer 115.

After transmissive substrate 100 is scribed, scribe marks 248 and 250 are "vented." Venting is the process by which optically transmissive substrate 100, such as a glass, is cracked at the location of the scribe so as to directionally propagate the crack through the thickness of glass substrate 100. The venting can be accomplished either manually or using an automated machine process.

A singulation process embodiment preferred over the square glass singulation process described in connection with **Figures 18** through **Figure 25** will now be described. **Figure 26** shows an embodiment where the perimeter of transmissive substrate 100 follows the generally round perimeter of wafer 115. Since the perimeter of transmissive substrate 100 follows the round perimeter of wafer 115, the same equipment used to handle wafer 115 may be used to handle substrate 100.

As shown in **Figure 26**, wafer 115 with round glass substrate 100 is mounted to a vacuum chuck with pattern-side 117 of wafer 115 facing in the up direction. Material is removed from

substrate 100 in the X-direction to reveal top exposed wafer 270 and X-surface substrate 272 and in the Y-direction to reveal side exposed wafer 274 and Y-surface substrate 276 as shown. As shown in **Figure 27**, at top exposed wafer 270, material is removed from wafer 115 parallel to X-surface substrate 272 to form X-registration 278. At side exposed wafer 274, material is removed from wafer 115 parallel to Y-surface substrate 276 to form Y-registration 280.

With X-registration 278 and Y-registration 280 machined into wafer 115, wafer 115 is flipped over so that pattern-side 117 is facing down. Now, cuts similar to those shown in **Figure 21** and **Figure 22** may be made into backplane 120 using the relative registration provided by X-registration 278 and Y-registration 280. Transmissive substrate 100 may now be scribed and vented as discussed in connection with **Figures 23, 24, and 25**.

This round glass method is preferred since it eliminates the extra handling tools needed to handle a square piece of glass. This is especially acute when the diameter of wafer 115 is 8.0 inches. There, the diagonal of a square piece of glass exceeds 11.3 inches -- a length in which most existing equipment in this area is not capable of handling.

Once transmissive substrate 100 is vented, the remaining silicon material at the scribe locations unifying wafer 115 can

be easily broken and the individual display assemblies separated as shown in **Figur s 28** and **29**. **Figur 28** shows the separated individual display assemblies 300 from an X-direction and **Figure 29** shows the same assemblies 300 from a Y-direction.

5 An alternative to the above assembly, cutting, scribing, and venting process is to divide the substrates individually. For example, wafer 115 can be cut into individual device, then assembled to an individual transmissive substrate panel of substrate 100. In this manner, the scribe marks on wafer 115 can be used to cut wafer 115 into the individual display device from the top (i.e., circuitry patterned-side 117 facing up). Optically transmissive substrate 100 components can then be properly aligned and coupled to wafer 115 in a process similar to that described above with coupling substrate 100 to wafer 115. A third alternative is to assemble a similarly sized transmissive substrate 100 to wafer 115 prior to dividing the assembly into individual display devices 300. In this embodiment, concerns over cutting wafer 115 from the non-patterned side are addressed by mounting the camera below the dicing saw to align the cuts to the scribe marks on the patterned side of wafer 115.

Once the individual display devices 300 are separated from the wafer, they are either filled with liquid crystal material or, if already filled, sealed at their fill ports to retain

liquid crystal material 220 in cell gap 207. Recall that in **Figure 8** and the accompanying text, perimeter seal material 150 surrounded the wafer to define each individual display device or assembly and fill port 167 was left to allow the placement of liquid crystal material 220 in display area 160. Where liquid crystal material 220 is located in cell gap 207 of display area 160 of device 300, fill port 167 is filled by the application of an ultraviolet cure adhesive that is cured with an ultraviolet light.

Figures 30 and 31 illustrate the situation where the individual display devices 300 have not been previously filled with liquid crystal material 220. In **Figure 30**, singulated device 300 is put in vacuum chamber 315. Chamber 315 then is evacuated until the pressure reaches 10^{-1} Torr. Display device 300 is lowered so that the end of device 300 having fill port 307 contacts liquid crystal material 310 in bath 305. Fill port 307 may be of fill port 167 shown in **Figure 8**. Chamber 315 is pressurized with air to atmospheric pressure and the pressure difference between cell gap 207 (**Figure 11**) and the ambient pressure forces liquid crystal material 310 into display area 160 as shown in **Figure 31**. Once the individual display device 300 is filled with liquid crystal material 310, the excess liquid crystal is cleaned off fill port area 307 and an ultraviolet cure adhesive is applied to fill port 307. The

adhesive is then cured with ultraviolet light to seal display area 160 of display device 300.

An singulated fill embodiment preferred to that described in connection with **Figure 32** and **Figure 33** will now be

5 described. **Figure 32** shows singulated device 300 position with fill port 307 facing up within chamber 315. First, air is vacuumed from chamber 315. Then, a drop of liquid crystal material 310 is placed over fill port 307 by dropper 301. Dropper 301 is preferably in the shape of a short, sturdy, 10 little tea pot having a spout and a handle. With perimeter seal area generally spanning one-half inches and fill port 207 generally spanning two microns, surface tension holds liquid crystal material drop 311 in place.

15 With drop 311 in place, chamber 315 is pressurized. **Figure 33** illustrates chamber 315 in the pressurized state. As chamber 315 is pressurized, the pressure within viewing area 160 is less than the pressure in the remaining area of chamber 315. Due to this pressure difference, liquid crystal material drop 311 is forced into viewing area 160 as assisted by gravity. Excessive 20 liquid crystal material 311 is cleaned off. Fill port 307 is then plugged with ultraviolet cure adhesive and this adhesive is then cured with an ultraviolet light.

Figur 34 illustrates a cross-section of individual display 300 from an X-direction, whereas **Figure 35** shows the same

assembly from a Y-direction. **Figures 34 and 35** show liquid crystal material 310 positioned in cell gap 207 between optically transmissive substrate 100 and wafer 115.

Figure 36 shows micro liquid crystal display 400 in a state where micro liquid crystal display 400 is ready to be packaged into a micro liquid crystal display panel. First, overhang 330 of substrate 100 shown in **Figure 35** is removed by, for example, applying a scribe or laser to the glass overhang of display 300. Then, the material comprising alignment layer 135 disposed in offset portion 119 is removed to expose land pads 405 and other electrical components located in that area. Alternatively, this area may have been masked or alignment layer 135 may be retained only to be pierced using a push through technique. Land pads are electrical contact pads that permit electrical communication between the circuitry within micro liquid crystal display 400 and devices external to micro liquid crystal display 400 such as a device driver located on a driver board. Micro liquid crystal display 400 may then be enclosed within an anti-static bag and packaged for shipment with other displays 400 in a box or some other convenient shipping container.

Micro liquid crystal display 400 may be integrated with other existing components. For example, **Figure 37** shows single-chip radio 500 manufactured by Lucent Technologies Inc. in Allentown, Pennsylvania in its Microelectronics Group. Single-

chip radio 500 may be thought of as a low-power, tiny
radio/microphone made of aluminum nitride on a silicon surface
and built by using silicon micromachining and etching material
from a silicon integrated circuit such as wafer 115. As a
5 radio, single-ship radio 500 works towards communicating audible
signals through wireless transmission as encoded in
electromagnetic waves, preferably in the approximate frequency
range from 10 kilohertz to 300,000 megahertz. As a microphone,
single-ship radio 500 works towards converting sound waves into
10 an electric current that may be fed into an amplifier, a
recorder, or a broadcast transmitter.

As shown in **Figure 37**, base 510 of single-chip radio 500
measures approximately 600 microns (0.6 millimeters) in length.
Give its small size and construction out of wafer material,
single-chip radio 500 may be integrated into wafer 115 and
disposed in convenient locations 503 along offset portion 119
indicated in **Figure 36**. The perimeter of wafer 115 may also be
extended out beyond the footprint of substrate 100 in any
direction to provide more convenient locations 503. The
20 integration of single-chip radio 500 of **Figure 37** into micro
liquid crystal display 400 permits building miniature portable
devices such as head mounted display products or telephone
watches that will use voice recognition through single-chip

radio 500 and have static and dynamic, real time video capabilities through viewing or display area 160.

An essential part of single-chip radio 500 for use in miniature portable devices is small radio frequency (RF) filter 520 illustrated in **Figure 38**. RF filter 520 is a component that shields unwanted radio frequencies and is manufactured by Lucent Technologies Inc. in its Microelectronics Group. For any instrument that both converts sound signals into a form that can be transmitted to remote locations and receives and reconverts waves into sound signals, an RF filter is used to protect the receiver on the instrument from the transmitter on the instrument. In conventional cell phones for example, the RF filter, made of a ceramic material, is by far the largest single component. **Figure 38** illustrates a size comparison between U.S. penny 522, conventional ceramic filter 524, and miniature RF filter 520.

Figure 39 shows a tank circuit 530 also built by Lucent Technologies Inc. using silicon micromachining techniques. Tank circuit 530 includes inductor 534. Inductor 534 is a simple loop of wire that helps determine the proper frequency for communications in a miniature portable device. Inductor 534 is shown warped away from silicon surface 536 in the shape of a taco shell. First flat plate 540 and second flat 542 comprise capacitor 548. With capacitor 548 storing an electric charge,

inductor 534 and capacitor 548 together determine a frequency that is proper for communications telephone watches. For tank circuit 530, the frequency may be established at the 1960 MHz required to communicate using the worldwide cellular PCS network.

In the preceding detailed description, the invention is described with reference to specific embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader scope of subject matter as set out in the claim terms. The written and drawing specification is, accordingly, to be regarded in an illustrative rather than a restrictive sense.